The hibernating mobile phone: Dead storage as a barrier to efficient electronic waste recovery

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ABSTRACT

Hibernation, the dead storage period when a mobile phone is still retained by the user at its end-of-life, is both a common and a significant barrier to the effective flow of time-sensitive stock value within a circular economic model. In this paper we present the findings of a survey of 181 mobile phone owners, aged between 18–25 years old, living and studying in the UK, which explored mobile phone ownership, reasons for hibernation, and replacement motives. This paper also outlines and implements a novel mechanism for quantifying the mean hibernation period based on the survey findings. The results show that only 33.70% of previously owned mobile phones were returned back into the system. The average duration of ownership of mobile phones kept and still in hibernation was 4 years 11 months, with average use and hibernation durations of 1 year 11 months, and 3 years respectively; on average, mobile phones that are kept by the user are hibernated for longer than they are ever actually used as primary devices. The results also indicate that mobile phone replacement is driven primarily by physical (technological, functional and absolute) obsolescence, with economic obsolescence, partly in response to the notion of being 'due an upgrade', also featuring significantly. We also identify in this paper the concept of a secondary phone, a recently replaced phone that holds a different function for the user than their primary phone but is still valued and intentionally retained by the user, and which, we conclude, should be accounted for in any reverse logistics strategy.

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1. Introduction

Given the global prevalence of supply and demand, and linear economic models (built upon the ideas of neoclassical economics and its theories of consumption), the goal of continuous growth is predicated upon intensive energy and material use in both the production and consumption phase (Mont and Bleischwitz, 2007). However, in order for these linear economic models to work it must also be assumed that there is an unlimited supply of natural resources and that the planet has a limitless capacity to assimilate the waste created by these processes (Cooper, 1999; Stahel, 1998), an assumption that is clearly flawed. At present, the European Union consumes approximately 25–30% of all metals globally produced, but is only responsible itself for 3% of production (Department for Environment Food and Rural Affairs, 2012), resulting in an increasing dependency on the import of raw materials.

Although it has been apparent for some time that such a linear economy is unsustainable, both in terms of long-term maintainability and sustainable development, it has become problematic to decouple resource throughput and move to more circular economic models, as it would slow down economic growth, and this would undermine 'growth is good' policies (Stahel, 2010).

An alternative to the current linear economic model is the concept of a circular economic model (Hawken et al., 1999; Stahel and Reday, 1976/1981; McDonough and Braungart, 2002), incorporating biologically inspired production models and closed-loop, cradle-to-cradle, industrial cycles (McDonough and Braungart, 2002). The circular economy provides an opportunity to mitigate (but not eliminate) the negative ecological, social, and economic consequences generated by the increased turnover of consumer electronics (Zhang et al., 2012) by not only ensuring that the lifetime of products is increased (where appropriate) (Cooper, 2010; Stahel, 2010), but also by ensuring that end-of-life products (and the precious materials that they contain) are returned back into the loop and are not land filled, incinerated or lost (Darby and Obara, 2005).

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Turning attention towards mobile phones, there are clear issues surrounding the disposal of these small electrical products at their end-of-life. Polák and Drápalová (2012), for example, have shown that a very small percentage, between 3 and 6%, of old mobile phones in the Czech Republic are ever actually returned for recovery or recycling. Similar low values have also been reported in Germany (Buchert et al., 2015) and from elsewhere around the world (Tanskanen, 2013; Chancerel and Rotter, 2009). Compounding this issue, mobile phones are material rich, often containing more than 40 different elements (UNEP, 2009; OECD, 2010), many of which are classified as having a high risk of supply disruption (British Geological Survey, 2012). Although the relative weight of each mobile phone's metal content is low, for example copper, gold, palladium, and silver only make up 13.2% of a mobile phones total weight (Yu et al., 2010), mobile phones represent a significant material resource. For example, although mobile phones are composed of only 0.04% gold by weight (an average gold content of 44 mg), this concentration of gold is approximately 200 times greater than the concentration found in a South African gold mine (Takahashi et al., 2009). Therefore, the issue of dead storage is problematic if these hibernating devices are not returned back into a circular loop: the resources they contain leak out of the system and are essentially lost. This results in increased production and the associated impacts as well as harvesting of a finite supply of raw materials, which is unsustainable when trying to meet the modern world's insatiable demand.

Although official figures are not known, the Green Alliance (2015) claims that in UK homes, there were between 28 and 125 million mobile phones in hibernation; even the conservative end of this estimate represents a significant resource. As such, hibernated mobile phones represent a significant barrier to the effective recovery of electronic waste within a circular economic model. In this paper, as part of the Closed Loop Emotionally Valuable E-waste Recovery project [CLEVER], we report on findings of a study that explored mobile phone ownership, reasons for hibernation, and replacement motives (mobile phone obsolescence) amongst 18–25 year old university students living within the UK.

2. Hibernation

To be clear, the definition of 'hibernation' we use here is that as defined by the work of Murakami et al. (2010); where the 'possession span' is the combination of the 'duration of use' (during which the consumer is using the goods) and 'dead storage period' (when the goods are no longer in use). It is the dead storage period which we define as hibernation here. Others in the literature discuss hibernation in similar terms such as 'household storage' (when phones have been taken out of service) (Jang and Mincheol, 2010); 'stockpiling' (the storage of any e-waste product at home or at off-site facilities before end-of-life management) (ICF International, 2011; Wagner, 2009); or 'permanent hoarding' (Used Electrical and Electronic Equipment [UEEE] in the home but no longer used) (Haig et al., 2011). We avoid using the term stockpiling to prevent confusion with the retaining of stock within the system by manufacturers for reprocessing or remanufacture; here, hibernation refers to the mobile phone and suggests a latent value that although steadily reducing, could be 'reawakened' and recaptured.

For a circular economic model to function effectively, the loss of resources and value within the loop must be reduced. It stands to reason that any leakage, including hibernation, will have manifold effects, as not only are the precious resources lost for reinvestment as remanufactured components or reused products, but also the shortfall in material will necessitate a rebalance with virgin stock. Further compounding the environmental impact of rebalancing

with new products or components, it has been shown that the majority of emissions are from manufacture, depending on the system boundary, as opposed to the products' use over lifetime (Green Alliance, 2015; Suckling and Lee, 2015). In the context of these circular economic models, the primary concern is not with the movement of product from manufacturer to user to disposal, but with a systemic approach of maintaining high quality *stocks* through appropriate *flows*. The mobile phones and the components and materials within them represent the stock. This stock of mobile phones provides the service of communication. By maintaining this stock for the appropriate amount of time, the service of communication can be provided with least impact. The flows of materials necessary to achieve this must be carefully controlled to minimise the inputs from the natural world, and maintain them within the circular economy.

As proposed in the development of a mobile phone product-service system (PSS) by authors Lee et al. (2015) and Wilson et al. (2015), mobile phones are considered the stock, the flow of which is managed around the system based upon unit/component *value*; value here being contingent upon environmental, economic, and technological indicators. Social values are not considered in this treatment, these must also be considered before something can be considered truly sustainable (Lee et al., 2015). As shown in Fig. 1, the value of stock can inform and direct channel flows, by, for example, directing used mobiles phones for (in order of most to least sustainable) reuse or remanufacture; or at a component level, towards stockpiling (reusing the components for mobile phone remanufacture) or reprocessing.

Once products and their internal components (e.g. circuit board, battery, etc.) become obsolete (likely through a combination of physical and psychological obsolescence types, as defined in Table 1 below) they no longer hold sufficient economic value for reinvestment towards reprocessing, recycling or export (Geyer and Blass, 2010; Lee et al., 2015; OECD, 2010). For example, phones operating with antiquated or discontinued software systems with no possibility of upgrade have very limited economic resale value for reuse in the original geographical location (Green Alliance, 2015) (but may still hold functional value in regions where a lower specification is the norm). Furthermore, the shelf-life of physical components are also limited, with the functional value of a CPU dropping as newer and more capable versions (increased clock speeds, number of cores, &c.) become the norm and more cost effective as a result (Lee et al., 2015). Therefore, the stock and flow of electronic goods, mobile phones in particular, is predicated upon finite lifespans for given geographical locations (Murakami et al., 2010).

In addition to the eight identified categories of obsolescence, is the concept of 'planned obsolescence', a term that has existed since 1932 (Chapman, 2005), but has been a practiced corporate strategy since the economic model of supply and demand embraced mass production and market. It is perhaps unsurprising that certain producers of goods have manipulated obsolescence as a way of increasing consumption as a means of maximising profit (Packard, 1960). A classic early example of planned obsolescence was enforced by the Phoebus cartel, a consortium of manufacturers in the early part of the last century, that fixed higher prices and restricted the life expectancy of light bulbs produced by cartel members (Aladeojebi, 2013; Reich, 1992). Even Apple's flagship mobile phone, the iPhone 6s Plus, only has an assumed use phase of three years according to their environmental report (Apple, 2015). Although previously mobile phones purchased under contract were subject to obsolescence due to incompatibility issues when changing service provider, the ability to 'unlock' the handset has enabled users to switch providers and keep their phones, or conversely, has allowed the same handset to be used by multiple users with different service providers. However, manufacturers
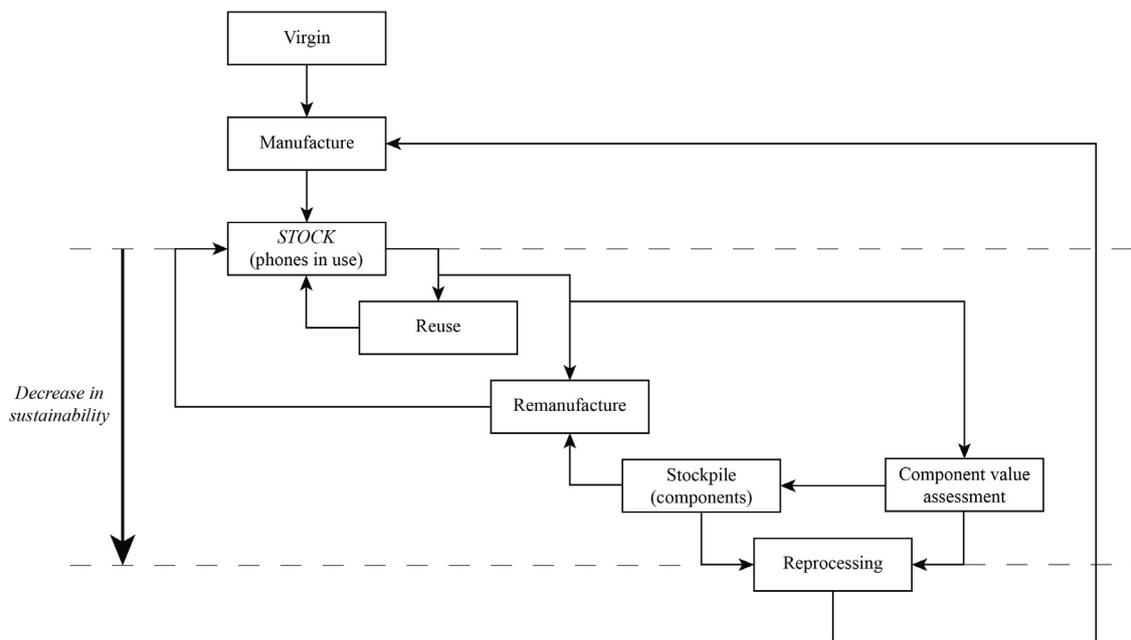
Fig. 1. Stocks and flows system of a mobile phone (adapted to show hierarchy of sustainablity, from Lee et al. (2015)).

and retailers cannot be considered the only drivers of the throw-away society, which as stated above, also relies on the decision making processes and actions of consumers (Burns, 2010); the user being the focus of this paper, and not the under pinning corporate strategy.

It is important to consider that this circular process is time contingent, and that the value of stock, here phones and components, is based upon the length of time before they flow into reverse logistics channels, for example returned to the shop of initial purchase, moving from the consumer back into the production chain. The optimal extraction of economic value from a used mobile phone is first through re-use, then remanufacture and finally recycling. Re-use is the most time critical as the phone must still be functional before all of the modes of obsolescence in Table 1 become acute. Obsolescence may be dictated by a single component within the phone, meaning the functionality of the phone as a whole is determined by the most susceptible component. Remanufacture has a longer time frame due to the increased flexibility of being able to replace only those components which are obsolete. Finally, recycling is the recourse which should be taken when all other channels become unavailable. It should be noted that under current economic conditions recycling does not cover the expense of reverse logistics of collecting the old phones (Geyer and Blass, 2010). A consequence of this rapid depreciation of economic value, hibernation, and the delay this brings to reintroducing the product and its components back into the system, presents itself as a particular challenge to effective use of a mobile phone prior to it becoming an e-waste. The depreciation of economic value arises from the age and headline specifications of the phone relative to those coming onto the market: the older it is, the less value it holds to those who may wish to purchase it, compared to the newer models.

Several studies from across the globe have investigated hibernation (although not necessarily as their primary focus), consistently finding large and significant percentages of users who keep their old phones once replaced with new, preventing their old phones re-entry into the system (Table 2). Interestingly, most participants cite that they had kept their old phones as a back-up or spare to their current phones. This suggests that the perceived value (we place emphasise on this value as perceived due to the subjective and transient nature of the relationship rather than a fixed external value, such as actual economic component value at a given point in time) of owning a working device and hence the continuation of the ability to communicate or to be connected to the wider world is higher than the perceived economic/environmental value of returning the device. Mobile phones have a perceived residual value (economic, environmental or functional) to the user, irrespective of actual end-of-life value, which has inhibited the return of many of these hibernated devices (Hanks et al., 2008; Jang and Mincheol, 2010; Rathore et al., 2011). This perceived value is also weighed against the users knowledge (or lack thereof) with regards to how and where to return end-of-life devices (Yin et al., 2013; Yla-Mella et al., 2015; Wilhelm et al., 2011), a common issue with many small electronic products (Geyer and Blass, 2010; Cole et al., 2016; Darby and Obara, 2005). Furthermore, this also suggests that a large percentage of phones that are hibernated still work to some extent, hence their value as a backup (logically, a broken phone would not work as a suitable replacement and would be retained for other reasons, such as keeping for spare parts or not knowing what to do with it).

Several studies have also shown participants to have in excess of the assumed one phone needed as a spare (Huang and Truong, 2008; Ongondo and Williams, 2011; Yla-Mella et al., 2015), suggesting that although a recently replaced phone may be initially kept as a spare, once they are themselves relegated with a newer replacement spare, the original spare phone is still retained.

Although it is clear that the retention of old working mobile phones after the purchase of a new phone is both historic (in that similarly high rates have been observed over the past ten years, although pre-smartphone data is not widely available) and a worldwide phenomenon, what is not so clear are the quantities of phones being retained and how long these old phones have actually been kept for; what, in real terms, is the duration of hibernation that needs to be reduced? Here, we explore this question within the context of UK university students.

Table 1
Eight categories of obsolescence.

Category of obsolescence	Description
Absolute	Physical product failure, where through use or misuse a product ceases to function due to wear and tear or as the result of breakage (Cooper, 2004; Granberg, 1997). Although assumed to be the most common reason that appliances are discarded, in the UK the minority of objects are broken beyond repair when replaced (Cooper and Mayers, 2000; Mayers, 2001)
Functional	The inability of a product to meet the functional needs of the user when compared to other, newer, products. Functional Obsolescence is based on objective criteria such as economic depreciation, and new situations that affect need, such as such as buying a larger car after the birth of children (Cooper, 2004), rather than subjective changes in the perception of the user, such as taste, fashion and status
Aesthetic	How a product looks in the context of cleanliness, wear and tear, newness and whether this is appropriate to the object (Burns, 2010; van Nes et al., 1999), and furthermore, how a product corresponds with relevant image concepts, such as style, fashion, novelty and prestige (Burns, 2010; Kostecki, 1998). Jeans, as an example, can be both fashionable and pre-worn whereas there is an expectation for consumer electronics to be clean and pristine
Economic	The cost of a product, and when it becomes financially advantageous to replace the product. This could be when the existing product has a low performance/cost ratio when compared with a potential replacement (Kostecki, 1998; van Nes et al., 1999), or when the cost of repair, maintenance, or upgrade of a product is greater that the purchase price of a replacement (Cooper, 2004)
Technological	When a product becomes relatively inferior to a newer product, which may have more features/functions, such as improved computer processor speed (van Nes et al., 1999), or has changed completely as a result of advances or revolutionary steps in technology or knowledge, such as the creation of the smart phone
Ecological	When a new product has a less harmful impact on the environment than the existing one. Ecological Obsolescence in isolation is less likely to occur when the ecological gain from the replacement device has comparatively little value due to the way resources are priced. A water saving shower may not cover its replacement cost due to the comparatively low value placed on water in the UK
Psychological	This occurs when a newer product has greater emotional value, or the current product has acquired negative emotional value. This may follow when an item has been given as a gift, and therefore is endowed with greater emotional value, thus making the existing product obsolete (van Nes et al., 1999). This is different to aesthetic obsolescence, which concerns cosmetic or decorative values
Societal	When changes in societal norms or changes to legislation or standards (Burns, 2010) makes a product obsolete. One change in societal practice that illustrates this is the use of snuff, ground tobacco, which has not been in popular use since the 19th century. Equally, branded ashtrays seen inside public houses in the UK no longer serve their purpose now that smoking is illegal in public buildings

Table 2
Studies that have investigated hibernation.

Year	Sample	Hibernated	Reason for hibernation after replacement
2006	Survey of 435 university students in USA	52.8%	The authors assume there to be a perceived value, or knowledge that disposal is harmful to the environment (Hanks et al., 2008)
2006	Survey of 1090 participants across Korea	40.3%	Not returned to retailer due to perceived economic value (Jang and Mincheol, 2010)
Pre-2008	Survey of 79 participants across USA and Canada	51.8%	As a backup; as an emergency spare; pack rat (hoarder); lazy; don't know; no reason (Huang and Truong, 2008)
2010	Survey of 2287 university students in UK	61%	Kept as a spare phone (77.1%); did not know what to do with it (30.1%); thought it was not worth anything (23.5%); valuable information stored on handset (21.2%); plan to give away later as a gift (16.3%); plan to send away for safe disposal (9.3%); keep to use the spare parts (8.1%); do not know (4.3%); plan to sell at later date (4.2%;) old technology is collectable (3.5%); plan to trade or sell against another (3%); other reasons (1.4%) (Ongondo and Williams, 2011)
Pre-2011	Survey of high income groups and low income groups across India	51% and 36% respectively	The authors assume that phones are retained due to a perceived value of a working phone (Rathore et al., 2011)
Pre-2011	Survey of 254 university students in USA	67%	Kept as a backup in case of damage or loss. Guilt of throwing away old phones (Wilhelm et al., 2011)
2011	Survey of 1035 participants across China	47.1%	Did not know where to send the phones (45.9%); rather give to friends/family than recycle (28.3%); afraid of privacy disclosure (17.7%); used as data storage equipment (8.1%) (Yin et al., 2013)
2013	Survey of 53 participants in Oulu, Finland	84.9%	Kept as a spare phone (55%); had not gotten around to returning it (38%); did not know where to take it (17%); thought recycling was troublesome (<4%) (Yla-Mella et al., 2015)

3. Methods

During July 2015, a survey was conducted by means of an online, self-completion questionnaire with mobile phone owners; distributed to a non-probability, purposive sample (i.e. aged between 18 and 25 years old, living and studying at a UK University, and owning a mobile phone). The young adult age group was selected as it represents the heaviest users of mobile phones that are also in the process of forming long term consumption habits (Wilhelm et al., 2011). The two sampling strategies employed were distribution via online social media channels (including Facebook and Twitter) and distribution through known gatekeepers (academic staff, hall wardens and university administrators) with access to student email lists across several UK university campuses (namely Loughborough University, Newcastle University, University of Bath, and the University of Surrey). Clearly using online sampling and surveying have both benefits and limitations. Online sampling could introduce self-selection bias into the results, with online social media channels and questionnaires excluding or under representing certain groups within

the target population (Bryman, 2015; Fielding et al., 2013). Low response rates are also notoriously difficult to overcome (Robson, 2002). However, the benefits of a wide distribution of sample (98% of women and 93% of men aged between 16 and 24 use social networks (Mintel, 2016)) and low cost in terms of resources (Robson, 2002) make such a strategy more viable than a random sample of the UK student population. Participants were recruited from across several UK Universities to avoid bias towards institutions that may foster a greater student understanding or ethos towards sustainability.

After piloting (amendments discussed at the end of this section), the questionnaire consisted of 22 questions; a combination of quantitative and open ended qualitative questions. A copy of the hibernation questionnaire can be found in Appendix A (Table A1. Hibernation Questionnaire). A short introductory paragraph at the beginning of the questionnaire stated that participants must be a University student, 18–25 years old, live in the UK and own a mobile phone. To ensure all participants met the inclusion criteria they were asked to provide their age, country of residence and employment status at the end of the questionnaire. Primarily, the open ended response questions were provided to allow the participant to offer a comment to clarify and/or expand upon preceding closed question answers. It was made clear to the participant that they were under no obligation to complete the survey or to answer every question, but it was suggested that completing every question (open and closed) and finishing the survey would be beneficial to the research project. No incentives were offered other than the opportunity for the participant to 'help to inform the design of the next generation of new and better electronic products and services'.

The first section of the questionnaire clarified the required sample variables and introduced the survey whilst the second section of the questionnaire established the details of the participants current mobile phone; an easy lead into the subject at hand. Respondents were asked to provide details of the model of the phone that they were currently using, as well as for how long they have owned it and how it came into their possession.

Section three concentrated on the respondent's replacement motives and actions with their prior mobile phone. First, participants were asked to provide details on the model of their previous phone, as well as how long ago they had purchased it and how it had come into their possession. Next, participants were asked to select all the reasons why they replaced their previous mobile phone with their current one; self-reporting and explaining in their own words the prominent reason for mobile phone obsolescence (Table 3). The category of obsolescence has been provided here for reference and was not stated in the questionnaire. Participants then were asked to select what action they had taken with their previous mobile phone once replaced with a new one (Table 4). Multiple choice answer options were randomised to avoid order bias.

The fourth section of the questionnaire explored historic mobile phone ownership and hibernation, asking when the participant had first owned a mobile phone; how many they have owned; and how many of their old phones they had kept. If the participant had indeed kept any old mobile phones they were asked to list approximately how long they had owned each one still in their possession and to select all the reasons why they had kept them. The option of providing an account in their own words was provided (Table 5). Answer options were once again randomised to avoid order bias.

The final part of the questionnaire asked for demographic information (age, gender, nationality, and employment status) to help describe the participant.

Prior to distribution, the survey was piloted to ascertain if there were any potential flaws in its design and to gain experience in analysing the data generated. Conducted in two phases, the questionnaire was piloted with 18 and 12 participants respectively using convenience samples with no specified demographic features other than a history of mobile phone ownership. Key modifications to the questionnaire included the changing of Question 7 multiple-choice answer options in line with an expanded literature review on types of obsolescence (the revised version is shown in Table 3), and reworking Question 14 to include the word 'approximately', due to participant concerns over recollection and specificity, and to be more guiding in the required data entry format. The edited question read as: How old are each of the old mobile phones that you have kept and still own? Please list approximately how long you have owned each old mobile phone (e.g. 3y 6m; 5y; 10y 6m NOT 3–10y or 3y+).

4. Results and discussion

From the initial 270 survey responses there were 181 eligible participants (*P*), once those not stated as being aged between 18 and 25 years old and living in the UK, and those that did not fully complete the questionnaire had been removed. It is understood that these results cannot reliably be utilised to represent the entire student population of the UK due to the limited sample size and self-selection bias. Of the 181 eligible participants, 57% were Female and 43% were Male, which correlates well with the

Table 3
Questions related to mobile phone replacement reasons.

No.	Question	Cat. of obsolescence
7	What was the reason for replacing your previous mobile phone with your current mobile phone? Please select all that apply	
	It was lost/stolen	Absolute
	It broke beyond repair	Absolute
	The technology is worn out	Absolute
	It didn't have the specific functions that I wanted	Functional
	I wanted a different contract with better features	Functional
	It was no longer novel, stylish or prestigious	Aesthetic
	It was no longer clean, shiny, or new	Aesthetic
	It cost too much money to repair (if broken)	Economic
	I was offered a free/discounted upgrade in my current contract	Economic
	I wanted a different contract with better cost value	Economic
	The technology was outdated	Technological
	It was bad for the environment	Ecological
	I am more emotionally attached to the replacement	Psychological
	It was no longer socially acceptable to use	Societal
	Other (please specify)	
8	In your own words, please explain the main reason why you replaced your previous mobile phone with your current mobile phone?	

Table 4
Questions related to mobile phone replacement actions.

No.	Question
9	What did you do with your previous mobile phone once it was replaced? Please select all that apply
	I kept it
	I took it to the recycling centre
	I left it at the store when buying a new one
	It was lost/stolen
	I gave it to friends/family
	I threw it in the general waste
	I donated it to charity
	I sold it to an individual
	I sold it to a store
	Other (please specify)

Table 5
Questions related to mobile phone hibernation reasons.

No.	Question
15	If you have kept any old mobile phones, for what reasons did you keep them? Please select all that apply I plan to sell at a later date I do not know why I think it's not worth anything I keep to use the spare parts Old technology is collectable I plan to trade against another Valuable information is stored on handset I plan to send away for safe disposal I do not know what to do with it I plan to give away later as a gift I keep it as a spare Other (please specify)
16	In your own words, please explain the main reason why you have kept any old mobile phones?

statistics published by the Higher Education Statistics Agency which state that 56% of students in the UK in 2014/15 were Female, and 44% Male (2016). The mean duration of current mobile phone ownership of these 181 participants was 14.43 months (1 year, 2 months). Although these figures cannot point to how long these phones *will* be owned for, it is interesting to note that 97.79% of mobile phones currently in use have been owned for three years or less, with an adjusted Fisher-Pearson standardised moment coefficient of 1.46 (0–60 month sample range), which as clearly shown in Fig. 2 describes a right-skewed positive distribution. Whilst this indicates that current phone ownership is predominately within the assumed lifetime as stated by many mobile phone manufacturers (e.g. Apple's three years (2015)), we cannot say how old these mobile phones are specifically as 14.36% (26 out of 181) were already used prior to current ownership.

4.1. Replacement and obsolescence

When questioned as to what the reason for replacing their previous mobile phone with their current mobile phone was, the survey revealed that technological obsolescence ('the technology was outdated'; $n = 67$; 37.02% of P); functional obsolescence ('it didn't have the specific function that I wanted'; $n = 52$; 28.73% of P); and absolute obsolescence ('the technology was worn out';

$n = 48$; 26.5% of P) featured significantly in participant replacement decisions (Fig. 3). For these participants, the reason for replacing their previous phones with their current one was primarily driven by the physical or operational characteristics of both the phone that they previously owned and the phone that they subsequently purchased. The actual and perceived discrepancy between these two phones (the 'old' and the 'new'), likely due to the introduction of novel features, functions or capabilities in newer phone models, or complete/part failure to function of their previous phone due to wear and tear, drove replacement behaviours as a function of the users need to bridge this perceived gap or deficiency. This is also supported by the comments of several participants, many claiming that functionality had deteriorated over time due to hardware issues or enforced software upgrades as well as new devices offering more utility, for example: "*the phone no longer consistently worked, turned itself off quite often, worked very slowly, apps often closed by themselves mid-use*", "[I] *wanted to use the internet on my phone to check train times, and be able to link it up to my activity tracker band*", and, "*The buttons on my old phone were not working, and I was unable to download apps because the software could not be updated to the most recent iOS.*" The results indicate that there is no one feature that drove replacement behaviour across all participants.

It was not clear from the statistics if the desire for new features is driven only by utility (for example, being able to use near-field communication [NFC] functionality for 'contactless' payment) or to an extent is an action driven by norms, roles or self-concept beliefs and values (Jackson, 2005) (for example, wanting the latest model phone with a fingerprint recognition function as a status symbol). The comparatively low (albeit still significant) number of respondents also citing aesthetic obsolescence ('it was no longer novel, stylish, or prestigious'; $n = 15$; $P = 8.29\%$; and, 'it was no longer clean, shiny, or new'; $n = 15$; $P = 8.29\%$) suggests that whilst some may replace based on social factors and image, physical obsolescence and utility are the dominate reasons for replacement.

However, it is also clear from this study that some forms of obsolescence are less relevant than others for mobile phones. At the other end of the scale, the comparatively low number of respondents citing societal obsolescence ('it was no longer socially acceptable to use'; $n = 8$; $P = 4.42\%$), psychological obsolescence ('I am more emotionally attached to the replacement'; $n = 4$; $P = 2.21\%$), and obsolescence ('it was bad for the environment'; $n = 1$; $P = 0.55\%$), again reinforce the position of the mobile phone
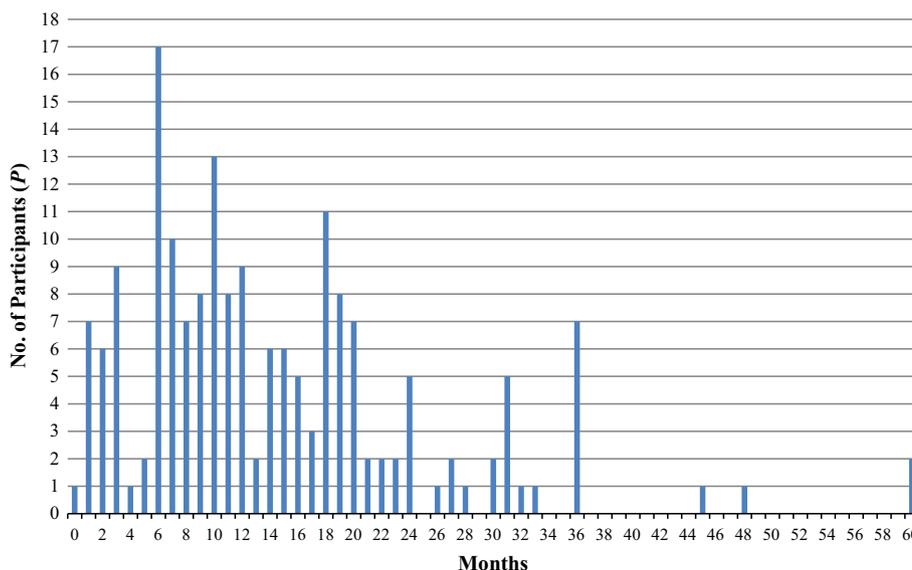

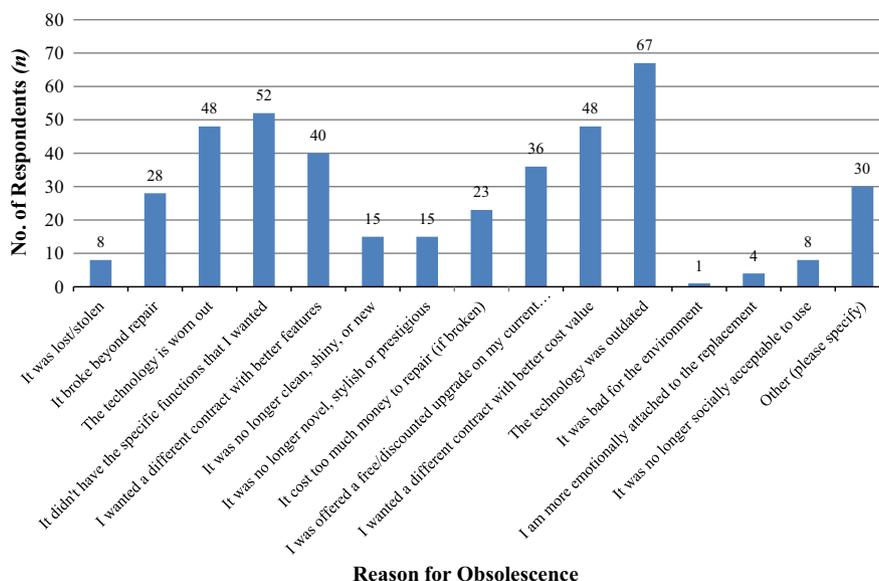**Fig. 2.** Length of current mobile phone ownership ($P = 181$).

Fig. 3. Reason for replacing previous mobile phone with current mobile phone (*P* = 181, *n* = 423).

as a utility tool with a consumer focus on the technology and functionality of the phone itself as opposed to acting based on psychological or larger societal concerns.

Economic obsolescence ('I wanted a different contract with better cost value'; *n* = 48; 26.52% of *P*) and service orientated functional obsolescence ('I wanted a different contract with better features'; *n* = 40; 22.10% of *P*) were both picked by 22 participants, indicating that better cost value was in part possibly due to an increase in offered features, such as more minutes or data for the same price. These types of obsolescence are also significantly stated as reasons for replacement, illustrating how the business model and service in which a phone operates can drive the replacement of hardware; indeed several participants used the phrase '*due an upgrade*', or something similar, as if to suggest that paying off the contract for the previous phone automatically *entitled* them to a better model.

However, the expectation of being 'due' an 'upgrade' could also be seen across several participants that had lived with functionally damaged phones or prevented repair until they could renew their mobile phone contract, for example: "*it was smashed and had stopped working and wasn't worth paying to fix my contract was also up for renewal*", and, "*it was old and was on the verge of breaking completely. At this time I happened to be due an upgrade*". Here, the participants have weighed the effort and financial cost of repairing their phone and instead decided to wait, with phones exhibiting various degrees of obsolescence, until they could be replaced with a new one.

Once their previous phones were replaced, 54.14% of the participants stated that they kept it; a significantly large proportion of respondents (Fig. 4), very much in line with other studies on mobile phone ownership and replacement, as previously discussed. Including the 5.52% of previous mobile phones that were lost/stolen or thrown into general waste, 59.67% of previous phones had not re-entered the system. Indeed, only 33.70% of previous mobile phones were returned into the system (recycling centre; left at store; gave to friends/family; donated to charity; sold to individual; sold to store), although not all channels can guarantee that a product and its components will be reused or remanufactured (for example, giving the phone to a family member doesn't guarantee that they will use it or return it themselves back into the system). It is interesting to note that less than 2% of all

participants chose to throw their phone into the general waste (1.10%), thus indicating that for the majority of respondents the replaced phone was still perceived as having residual value after use and/or that environmental concerns prevented irresponsible disposal.

4.2. Use duration and hibernation span

Participants had owned, on average, 5.08 mobile phones (excluding current mobile phone), with an average mean duration of use (assuming linear ownership and replacement) of 22.25 months (1 year, 10 months); less than two years. Although tempting to draw a correlation between 22.25 months of use and the typical 24 month duration of an UK phone contract (Which?, 2015), which it should be noted is significantly less than the life time of a mobile phone as expressed by manufacturers (for example, Apple (2015)), there is no way of knowing from the data collected whether all previous phones owned were tied to this duration of contract (they may, for example, have been on a pre-paid Pay As You Go [PAYG] service tariff). Mean duration of use was calculated by dividing the duration of mobile phone ownership by the number of mobile phones owned:

$$\textit{Mean Use Duration Per Participant} = \frac{12(y_1 - y_2) - t}{n}$$

where

y_1 = Year of study [2015].
t = How long have you owned your current mobile phone (in months)?
y_2 = In which year did you first own a mobile phone?
n = How many mobile phones have you owned (excluding current mobile phone)?

With an average participant age of 21.1, and an average first phone owned in 2005, this would also indicate that many participants were around 11 years old when they received their first phone. This has interesting ramifications for early purchase and disposal behaviours, as it may be assumed that any phone used by a minor (those under 18 years old) were likely the responsibility of the participant's parent/guardian rather than the participant themselves (in English law, minors do not have legal capacity to
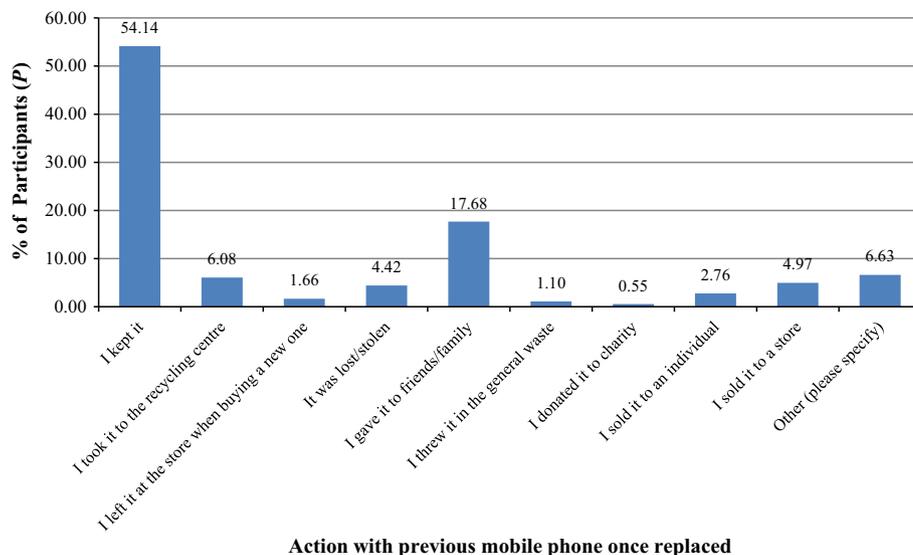
Action with previous mobile phone once replaced

Fig. 4. Action with previous mobile phone once replaced [% of *P*].

enter into a contract agreement, although they can purchase a PAYG phone).

When asked if they had any old mobile phones that they have kept and still own, the average participant response was 1.70 mobile phones (excluding current mobile phone); a total of 308 mobile phones hibernated across all 181 participants (Fig. 5). Approximately a third of the total number of mobile phones that the participants had ever owned were still in their possession (33.48%). If one were to take this as a proxy for UK university students, with the understanding that this can only be described as an estimate due to self-selection bias, and extrapolate the figure upwards accordingly (there were 2.27 million students in UK undergraduate and postgraduate study in 2014/15 (Higher Education Statistics Agency, 2016)), this would suggest a projected quantity of 3.85 million phones hibernated by UK higher education students only; a figure not too dissimilar to the 3.7 million as projected by Ongondo and Williams (2011).

The average duration mobile phones were kept by our participants who still owned one or more of their previous mobile phones (excluding current mobile phone), was 58.62 months (4 years, 11 months), with an average use duration per hibernated phone of 23.07 months (1 year 11 months). The average mean hibernation span of mobile phones kept was 35.55 months (3 years). Mean hibernation was calculated by subtracting the mean use duration for participants with hibernated phones from the mean duration of ownership for participants with hibernated phones:

$$Mean\ Hib\ Span\ Per\ Participant = \bar{x}_a - \left(\frac{12(y_1 - y_2) - t}{n} \right)$$

where

$\bar{x}_a$ = Mean Duration of Ownership for Participants with Hibernated Phones.

$\bar{x}_a = \frac{\sum x}{n}$.

$\sum x$ = The sum of the ages of retained old mobile phones (in months).

n = The number of retained old mobile phones.

From response to the question (converted into months) 'How old are each of the old mobile phones that you have kept and still own? Please list approximately how long you have owned EACH old mobile phone (e.g. 3y 6m; 5y; 10y 6m NOT 3-10y or 3y+)'.

In short, what these figures starkly illustrate is that on average for each mobile phone that has been owned by a participant (just under five years), that phone was kept in hibernation (just under three years) for longer than it was actually used (just under 2 years).

4.3. Reasons for hibernation

When presented with the question 'If you have kept any old mobile phones, for what reasons did you keep them?' (Fig. 6), over three quarters of the participants that have kept one or more phones responded with 'I keep it as a spare' (*n* = 106; 75.18% of *P* that hibernate one or more phones). Given the opportunity to explain why they have kept the phone as a spare, a large proportion of participants stated that they had kept one or more of their old phones as a sacrificial device for when they go to festivals, events, travelling, holidays or on nights out, for example: "*I use them as spares for occasions when my primary phone might become damaged or lost. I also use them whilst on holiday if I need a long battery life compared to my primary phone.*"; "[as a] *back up phone…just in case I do the student thing and lose it on a night out.*" and; "*If I fancied doing something where I would be worried that my smartphone would get broken*". Such comments reflect on both the actual and perceived fragility of their current phones as well as its value and functionality. A new phone must be protected, even from themselves and their own actions, whereas an older phone is more acceptable to be lost or destroyed, even if it still has a relatively high economic value and is fully functional, as it is mentally perceived as already being replaced and therefore replaceable (thus also suggesting that one can only have a single 'primary' phone at a time).

What is also interesting is that many of these hibernated phones still have an ongoing usable function and in some circumstances are shown to have a greater specific value (such as battery life or robustness) and a role for the participants, although it may not be on a day to day basis. Although the term hibernation has been applied to any old/previous mobile phones that have been kept, assuming spare or dead-storage to mean redundant to the primary phone, perhaps it would be more logical to view these spares as secondary phones.

But how many of these secondary phones does one need? As discussed in the literature review, several studies have shown par-
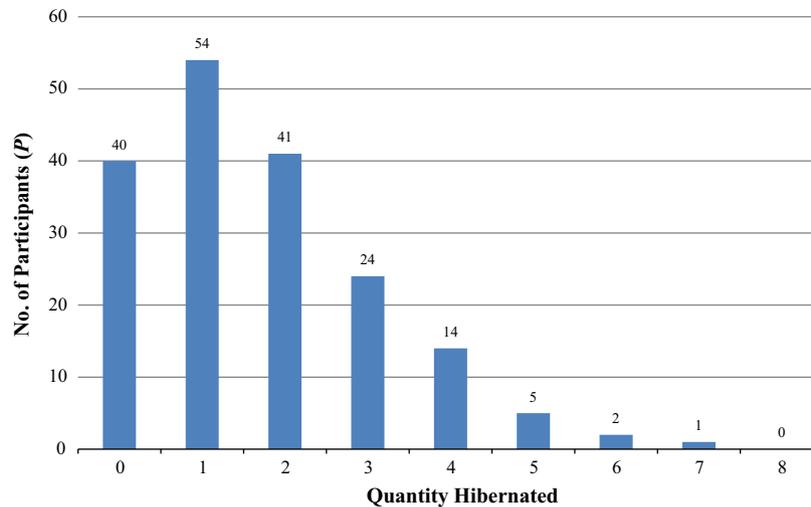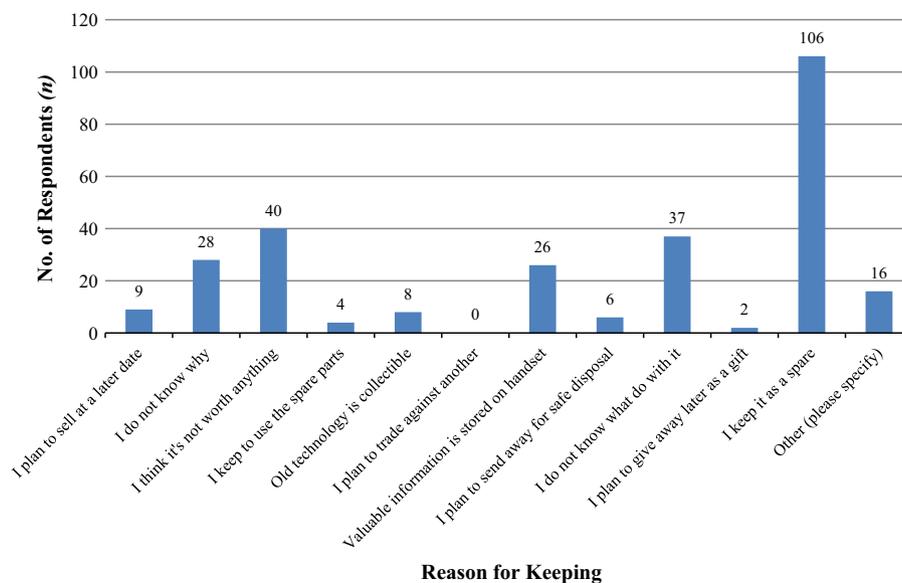
Fig. 5. Quantity of mobile phones in hibernation.

Fig. 6. Reasons for keeping previous mobile phones once replaced ($P = 141$, $n = 288$).

ticipants to have kept several mobile phones, beyond what one would assume to be useful (Huang and Truong, 2008; Ongondo and Williams, 2011; Yla-Mella et al., 2015). Interestingly, one participant commented: "*each one was kept as a spare and then as newer ones were bought I did not know what to do with the no longer needed spares*". This illustrates that as each phone moves along the chain, primary to secondary and beyond, the difficulty for the participant was determining what to do with the redundant spare, not the secondary phone. Another participant stated: "*I have kept old phones because they're not worth selling so not sure what to do with them...and also used my most recent old phone as an iPod*"; clearly the secondary phone for some participants still has a tangible value and use whereas older devices fall into the background with their value uncertain to the user.

This has clear repercussions for the stocks and flows model, given that by the point of which the secondary phone has *truly* become redundant (i.e. no longer a primary or secondary phone), one can assume that its economic value would have dropped – possibly contributing to the perception that it isn't worth anything, not knowing what to do with it, and not knowing why they have

kept it so long. Indeed, nearly a third of participants thought that their old mobile phones were not worth anything and so kept it ($n = 40$; 28.37% of P that hibernate one or more phones); a quarter did not know what to do with it ($n = 37$; 26.24% of P that hibernate one or more phones); and around a fifth did not know why they had kept it ($n = 28$; 19.86% of P that hibernate one or more phones). As one participant put it "*My habbit* [SIC] *is to keep them just in case and then forget about their existence*".

In addition to the concept of a secondary phone, clearly a lack of knowledge and understanding of the value of materials within these stored phones and the options for disposal has created a form of recycling lethargy – some participants have a vague idea that the phone may be of value beyond their own definition, but not all participants appreciate the implications of their delay in acting. As one participant stated: "*[I] don't know how to recycle them. In no rush to get rid of them but if I ever do will probably just google how to recycle phones*".

A further fifth of participants stated that they kept their old mobile phone because of the valuable information stored on the handset ($n = 26$; 18.44% of P that hibernate one or more phones).

Although valuable information can prevent a participant from relinquishing their phone based on data security issues, which was a concern for one participant: "*some are broken and the information is irretrievable by me but may not be to others*", a finding similar to Huang and Truong (2008) when interviewing Japanese participants, some participants cited emotional attachment as their reason for keeping their old phones. They may have kept their old phone due to its "*sentimental value*": it was the first phone that they "*got to pick (as opposed to a hand-me-down)*", a precious gift from a relative, or that the accumulated photo, data, and text had created a life 'narrative' with the product (paradoxically a design strategy *for* creating attachment (Chapman, 2009)), for example being the only device with their "*…secondary school's memory on*"; a form of memory time capsule. Both Wilhelm et al. (2011) and Yla-Mella et al. (2015) state that a reason for keeping a mobile phone could be due to attachment to the mobile phone itself; here we argue it is not the device per se that the user is attached to, as that is just a carrier, but more specifically the attachment is to the data contained within it. The unanswered question here is whether emotional attachment to the data and its life narrative qualities are permanently associated with the hardware creating and containing it, or whether it can be separated to allow the mobile phone to be recycled? Indicating a functional limitation towards this disembodiment at end-of-life, one participant stated that they "*Hadn't transferred all of my stuff over to the new phone*". Although outside of the scope of this paper, this issue should be explored further.

5. Conclusions

An effective circular economic model is contingent upon the flow of a stock around a system, governed in the case of mobile phones by time-sensitive and geographic values. At present, any mobile phone that is currently not being used or engaged in this model as a useful stock is a 'lost' resource, as this dormancy not only necessitates the processing of further raw materials to account for the market demand of the 'new', thus increasing demand on the worlds finite resources in addition to the myriad of ethical issues associated with the mining of said materials, but the myriad of different types of value contained within these phones diminishes over time. If stock is not effectively managed and moved, its value will diminish until reaching a state of depletion. Hibernated phones represent a surplus stock in use and hence an ineffective use of their time-limited value. Considering the hierarchy of sustainability as illustrated in Fig. 1, as value is diminished, the sustainability impact and cost of recovery and reuse/remanufacture/reprocessing inversely rises. The scale of the problem, unfortunately, is significant; as identified in this research currently only a third of replaced mobile phones owned by the participants have ever been returned into the system contributing to a projected sum of 3.85 million phones currently in hibernation by HE students across the UK. Perhaps more remarkable is the finding that for each replaced phone still owned by our participants, on average each of these devices were only used as primary phones for two years of their five year ownership; these replaced mobile phones are, on average, kept in hibernation (as secondary or redundant devices) for longer than they were ever actually used as a primary phone, pointing to a significant opportunity for shortening the period between end of use and return in order to maximise value return.

Also of interest from this study is the concept and ramifications of the 'secondary' phone; the immediately replaced phone has a use and value beyond hibernation. Although the dominant reason for non-disposal of a mobile phone is the keeping of it as a 'spare', consistent with the findings of several previous investigations into mobile phone use and disposal (for example, Ongondo and Williams (2011)), here we have unpacked this term and illuminated that it's expected utility and value differs from both that of a primary phone and a redundant phone. A secondary phone is not necessarily just a primary phone on standby, nor is it an unwanted possession.

Once primary use has ended and this three year secondary back up status has been initialised, return schemes that do not account for this secondary need will not succeed (as illustrated in the low take up of recycling and take back schemes unless a handset is truly antiquated) as they are still perceived to have a value and function, albeit different to the value and function of a primary phone. Considering it would be most beneficial from a business and environmental/economic/technological value perspective to have the primary phones returned after the initial two years of primary use, but a secondary phone is still required by the user, an opportunity is presented for a circular business to innovatively support this by, for example, replacing old primary phones with more appropriate secondary replacements (such as a refurbished older phone model with a robust screen, physical keys and a better battery life, possibly created and repackaged from the stockpiled and lower value components), alongside the purchase/leasing of a primary model. During this process of replacement, valuable information from the old primary phone (confidential or data to which the user is emotionally attached) could also be transferred to the new primary phone.

In addition, we have also observed what we have termed recycling lethargy, whereby the chain of continuous replacement and relegation has rendered older phones both redundant to the user and worthless from a value perspective. Incentivising the return of mobile phones before they become truly defunct could again be encouraged by implementing the approach outlined above, offering consumers benefits when purchasing/leasing their 'primary' phone and considering the value of the secondary phone to the user.

The results also indicate that reasons for replacement, driving the short two years of use, are predominately driven by physical obsolescence (technological, functional and absolute obsolescence respectively), due to the gap between the actual or perceived degradation of the users phone and the actual or perceived increase in functionality offered by a newer model; aesthetic or psychological concerns occurred but were less significant in the findings. The concept of being 'due an upgrade' also significantly featured as a replacement motive suggesting both a sense of entitlement and the perception, implicit in the word 'upgrade', that a newer phone is automatically better than an older/current phone. For a circular model to work, not only would the hibernation crisis need to be addressed, but also the notion that new technology (in this case, an entirely new phone as a replacement) is inherently better. As in the case of the mobile phone product-service system as described previously, we see one potential direction whereby the replacement of components by the service provider, could blur this line between old phones being synonymous with obsolete and new phones equating to a functional advantage, with features and individual components, such as cameras or processing capabilities, being individually serviced and replaced (possibly even framed as an 'upgrade') in answer to actual or perceived limited current functionality. From a stocks and flows perspective, this move towards functional replacement and maintenance could, the authors suggest, increase the duration of mobile phone use and reduce the motivation for total replacement due to the limited physical characteristics of a currently owned mobile phone (although appropriate reverse logistic channels, possibly via a maintenance service as discussed by Wilson et al. (2015), would need to be implemented

for recovering the replaced components). Modularity and maintenance could also support the concept of a secondary phone, whereby an increased battery life or robust screen could be purchased to satiate the user's requirements of their secondary device.

There is a clear difference in value and utility between primary, secondary, and redundant mobile phones to the user. We suggest that by providing *appropriate* mobile phones and components to the user, and recovering *inappropriate* mobile phones and components, depending on the value and utility that the user *actually requires*, dead storage as a barrier to efficient electronic waste recovery can be overcome by preventing mobile phones becoming truly redundant in the first place, therefore reducing the number of future mobile phones in hibernation.

Acknowledgments

Appendix A

See Table A1.

Table A1
Hibernation Questionnaire.

YOUR CURRENT MOBILE PHONE
The questions on this page are related to your CURRENT mobile phone ONLY.
Please ensure that you have answered each question before moving on to the next page.
1. What model is the mobile phone that you are currently using?
_____
2. How did you come to own your current mobile phone?
[ ] I purchased it (new) [ ] I purchased it (used) [ ] Given to me (new) [ ] Given to me (used)
3. How long have you owned your current mobile phone (in months)?
_____

YOUR PREVIOUS MOBILE PHONE
The questions on this page are related to your PREVIOUS mobile phone ONLY.
Please ensure you have answered each question before moving on to the next page.
1. What model was your previous mobile phone?
_____
2. How did you come to own your previous mobile phone?
[ ] I purchased it (new) [ ] I purchased it (used) [ ] Given to me (new) [ ] Given to me (used)
3. How long ago did you purchase/were you given your previous mobile phone (in months)?
_____
4. What was the reason for replacing your previous mobile phone with your current mobile phone? Please select all that apply.
[ ] It was lost/stolen It broke beyond repair [ ] The technology is worn out [ ] It didn't have the specific functions that I wanted [ ] I wanted a different contract with better features [ ] It was no longer clean, shiny, or new [ ] It was no longer novel, stylish or prestigious [ ] It cost too much money to repair (if broken) [ ] I was offered a free/discounted upgrade on my current contract [ ] I wanted a different contract with better cost value [ ] The technology was outdated [ ] It was bad for the environment [ ] I am more emotionally attached to the replacement [ ] It was no longer socially acceptable to use [ ] Other (please specify)
_____
5. In your own words, please explain the main reason why you replaced your previous mobile phone with your current mobile phone?
_____
6. What did you do with your previous mobile phone once it was replaced?
[ ] I kept it I took it to the recycling centre [ ] I left it at the store when buying a new one [ ] It was lost/stolen [ ] I gave it to friends/family [ ] I threw it in the general waste [ ] I donated it to charity [ ] I sold it to an individual [ ] I sold it to a store [ ] Other (please specify) _____
7. In your own words, please explain the reason why you did what you did with your previous mobile phone once it was replaced?
_____

YOUR MOBILE PHONE OWNERSHIP HISTORY
The questions on this page are related to your mobile phone ownership history (NOT including your CURRENT mobile phone).
Please ensure that you have answered each question before moving on to the next page.
1. In which year did you first own a mobile phone?
_____
2. How many mobile phones have you owned (excluding current mobile phone)?
_____
3. Do you have any old mobile phones that you have kept and still own? If so, how many (excluding current mobile phone)?
_____
If you HAVE kept any old mobile phones, please continue to the next question.
If you have NOT kept any old mobile phones, please continue to the next page.
4. How old are each of the old mobile phones that you have kept and still own? Please list approximately how long you have owned EACH old mobile phone (e.g. 3y 6m; 5y; 10y 6m NOT 3–10y or 3y+).
_____
5. If you have kept any old mobile phones, for what reasons did you keep them? Please select all that apply.
[ ] I plan to sell at a later date [ ] I do not know why I think it's not worth anything [ ] I keep to use the spare parts [ ] Old technology is collectible [ ] I plan to trade against another [ ] Valuable information is stored on handset [ ] I plan to send away for safe disposal [ ] I do not know what do with it [ ] I plan to give away later as a gift [ ] I keep it as a spare [ ] I haven't kept any old mobile phones [ ] Other (please specify) _____
6. In your own words, please explain the main reason why you have kept any old mobile phones?
_____

(continued on next page)

YOUR INFORMATION
The questions on this page are about you.
All the information you provide is completely confidential and will only be used for research purposes.
1. What is your age?
_____
2. What is your gender?
_____
3. What is your nationality?
_____
4. Which of the following categories best describes your employment status?
_____
5. Would you be willing to be contacted for a follow up interview?
[ ] Yes
[ ] No

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